4.—THE GEOLOGY OF THE HAMERSLEY SIDING AREA

BY

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CONTENTS.

ABSTRACT.

The country near Hamersley Siding, N.W. of York, is underlain by Pre-Cambrian metamorphic rocks. The main type is a microcline-oligoclase gneiss with which are intercalated two bands of coarse-grained quartzite containing chrome-muscovite. With the latter are lenses of other metamorphic rocks—plagioclase amphibolites ; hypersthene, cummingtonite, and grunerite metajaspilites ; and sillimanite-garnet-cordierite-anthophyllite rocks. These lenses are explained as the metamorphic equivalents of limestones, shales, cherts and sandstones in a great thickness of arkose, now represented by the gneiss itself.

Near the west side of the area, a granite mass is emplaced, causing a felspathisation of nearby gneiss. Granite dykes also traverse the metamorphics. Associated with the granite, and intrusive into both granite and gneiss, are appinites or hornblende granites—a rock type whose intrusive relationships have not been noted in Western Australia before. The last phase of igneous activity is represented by dolerite dykes.

The structure, as shown by the two bands of quartzite, is interpreted as a large anticlinal box-fold which pitches to the south.

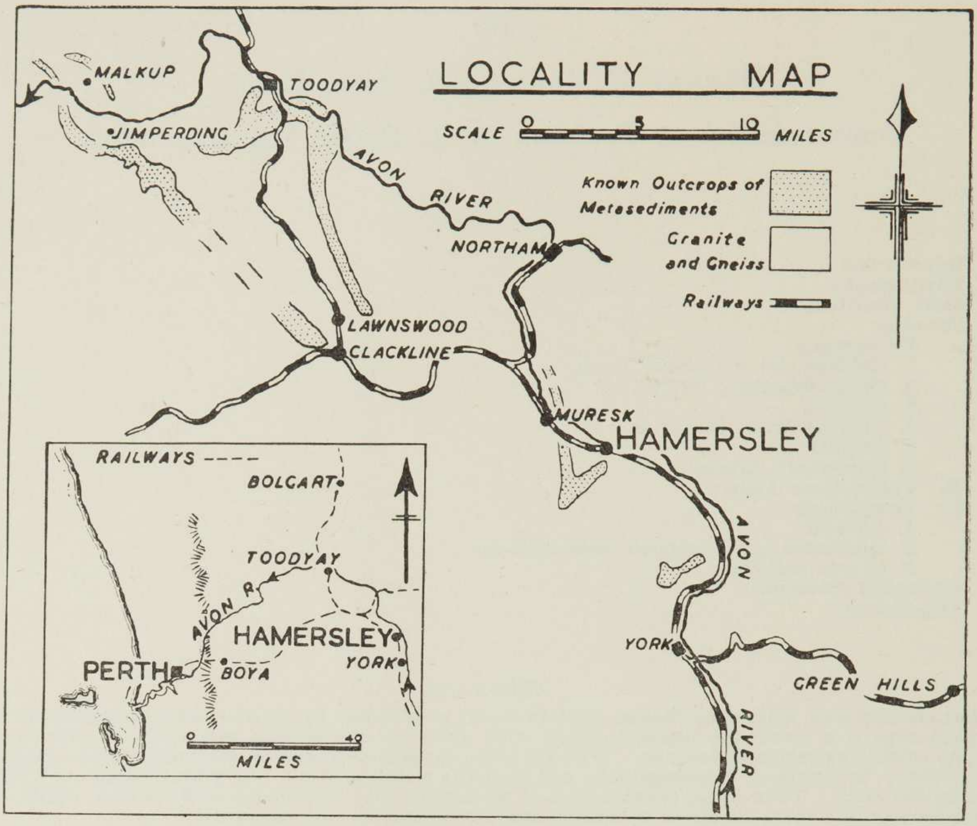
I. INTRODUCTION.

Hamersley Siding, which lies in the north-east corner of the area under review, is situated eight miles north-west of York, and the area mapped in 1948–49 measures 5 x 4 miles. It comprises the major part of three mixed farming properties which lie in the Avon Valley, a tract of highly productive agricultural land, which extends from Pingelly to Toodyay.

The region is part of the ancient West Australian Shield and contains gneisses, schists and quartzites of early Pre-Cambrian age. The accompanying map (text fig. 1) shows that the metasediments of the Hamersley Area are not structurally continuous with those of the Jimperding Series which outcrop at Jimperding (Prider, 1934), Toodyay (Prider, 1944) and Lawnswood (McWhae, 1948) ; but although these rocks may be lower or higher in the sequence than those of the Jimperding Series, I propose to tentatively class them as part of that series.

The field survey was undertaken by parties of students from the Geology Department of the University of Western Australia, during 1948 and 1949. Chain and compass traverses, linked to a framework of road pegs and boundary fences surveyed by the Lands and Survey Department, formed the basis of the mapping.

Major topographic features—the laterite mesas to the west of the area and the main stream courses—were mapped from aerial photographs taken by the R.A.A.F.



Text Figure 1.

Map of localities mentioned in the text.

Grateful acknowledgment for supervision of this work is due to Professor R. T. Prider and Messrs. A. F. Wilson and W. A. J. Saunders of the Geology Department of the University of Western Australia ; to many students of that department for assistance with the mapping and in the preparation of thin sections ; also to Mr. H. J. Smith for the photomicrographs ; and to Mr. A. D. Hosking and Mr. J. Lorimer for the photographs in Plate III. Thanks are due also to Mr. Edward Hamersley, of Hamersley Siding, for permission to work and camp on his property. Assistance received from the Government Research Grant to Universities is also gratefully acknowledged.

II. PHYSIOGRAPHY.

The area contains many of the features characteristic of the peneplained surface of the Western Australian Shield—the laterite hills of the Darling Ranges, and the gentle, undulating granite and gneiss country of the Wheat Belt. To the South and West, the area is bounded by partially dissected laterite mesas—remnants of the " Old Plateau." The northern and eastern boundaries lie in the broad, fertile, much-cultivated, valley of the Avon River. The land falls from the south and west to the north-east, and the main drainage follows this fall. The drainage channels may be classified into two groups :—

1. Short, intermittently-flowing, streams which head at the margin of the Avon Valley and flow directly down the valley sides into the river.

2. The major interior drainage of the area formed by Heale Brook (called Brekna Brook on the one-inch military map—York sheet) and its tributaries. The stream pattern here is closely related to the linear structures in the gneiss and quartzite (Plate I). Heale Brook crosses the area from south-west to north-east where it joins the Avon, being joined by Cobham Brook from the south-south-east. It is a rather unusual stream for this area in that it flows continuously throughout the year.

Four small residual hills of laterite remain in the centre of the area. These, like the laterites at Lawnswood (McWhae, 1948, p. 51) have sloping, not horizontal, tops ; but the dips on the laterites here are smaller than those in the Lawnswood area, averaging 4°.

The topography and soil are closely related to the two main rock-types—quartzite and gneiss. The gently-rolling gneiss country has but sparse outcrops and is cleared and cultivated. Quartzites, being more resistant, stand above the general level as hills with blocky outcrops and steep talus slopes.

In the central part of the area, where the quartzites strike north-east, the relief is such that strike and dip readings could be made, but elsewhere the " outcrops " consisted merely of boulders protruding from the soil.

Characteristic flora distinguish the main rock and soil types. The areas of gneiss support York Gum (*Eucalyptus foecunda*, var. *loxopheba*) and Jam (*Acacia acuminata*). Wandoo (*E. redunca*, var. *elata*) marks the quartzite and schist areas largely to the exclusion of York Gum and Jam.

III. FIELD DISTRIBUTION.

Most of the country (adjacent to Hamersley Siding) is underlain by a hybrid microcline-oligoclase-biotite gneiss. Interbedded with the gneiss, two discontinuous bands of quartzite, striking north-north-west, outcrop along the western margin of the area from the extreme north-west corner to (60N, 340W)*. Here, the strike changes abruptly to north-east and the rocks outcrop in this direction for 2½ miles, ending in a series of well-bedded quartzites and schists at Mt. Mackie. Paralleling the quartzite bands there are groups of metasedimentary lenses in the gneiss. These consist chiefly of plagioclase amphibolites, metajaspilites and garnet-cordierite-anthophyllite rocks.

In the central-western part of the area, a small body of fine-grained, massive granite outcrops. The granite and also its associated appinites are found as dykes of varying size traversing the gneiss.

The dolerites occur in several sets of dykes, the most prominent of which have a north-north-west trend. One large dyke of this group can be traced for a distance of 5 miles crossing the area from the north-west to the south-east corner. Minor fractures trending north-east and west-north-west are also occupied by dolerites.

Later superficial deposits consist of the laterite capping of a few small hills and the alluvium in the valleys of Heale Brook and the Avon River.

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* Co-ordinates for the Hamersley Siding Area are measured in chains from the north-east corner of Block Y8 on the Lands Department Litho.

IV. PETROLOGY.

A. PETROGRAPHY.

1. Gneisses and Associated Rocks.

(a) *Gneisses.*

The common hybrid gneiss is a medium-grained, uniformly banded, slightly porphyritic, microcline gneiss.

This gneiss is locally interbanded with aplitic and basic types, notably at a waterfall at (128N, 231½W) in Cobham Brook. Small basic patches of garnet-biotite gneiss occur in other phases of the complex. Microscopic examination revealed further variations ; aplitic gneiss rich in microcline, pure oligoclase-quartz gneiss, or variations between these two. The microcline-oligoclase-biotite gneisses often contain porphyroblasts of pink garnet surrounded by clots of biotite flakes. The number of types developed and the sudden transformation from one variety to another illustrates the hybrid nature of the rock.

The gneisses are variable in grain-size, as well as in chemical and mineralogical composition Interbedded with the medium-grained gneisses described above are fine-grained and finely banded metasedimentary types.

Variants of the gneiss are :—

(i) Microcline-oligoclase-biotite gneiss (25552)*.—This contains porphyroblasts of microcline up to 14 mm. in diameter set in a groundmass of smaller grains (1 to 2 mm. diameter) of microcline, albite-oligoclase, biotite, muscovite and quartz. The porphyroblasts are firmly intergrown with the groundmass and show no signs of post-crystallisation granulation. They consist of microcline with perthitic intergrowths of albite. Myrmekitic inclusions of quartz have developed in crystals of oligoclase by reaction with adjoining crystals of microcline during recrystallisation. Although the microcline is clear and unaltered, the oligoclase has a turbid appearance due to alteration to a fine aggregate of sericitic mica. Apparently the parent rock contained potash in excess of the amount required to satisfy all the microcline and biotite present. The oligoclase, at first, absorbed this excess potash into its own crystal lattice, but later the combination became unstable and the oligoclase disgorged its potash as a white sericitic mica. Quartz occurs in anhedral form amongst the microcline and oligoclase but also as small, round grains included in crystals of the felspars—possibly relics of original sand grains in the parent sediment. The biotite (X yellow, Z brownish-black) occurs in stout laths and shows incipient alteration to chlorite which gives it a greenish tinge. Associated with the biotite are plates of muscovite of comparable size (½ x 1 mm.).

(ii) Oligoclase-biotite gneiss (25597).—Although lacking in microcline this gneiss is not basic, but rather tends towards the aplitic type.

The handspecimen, collected at the waterfall in Cobham Brook, shows the hybrid nature of these rocks. Parts of the specimen are pure aplite (containing only oligoclase and quartz) whereas other parts contain up to 50 per cent. of garnet and biotite. The rock is traversed by several epidote veins near which the alteration of biotite to chlorite is almost complete ; within 1 cm. of the veins the oligoclase undergoes saussuritisation instead of the usual sericitisation which prevails elsewhere.

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* Numbers in parenthesis refer to specimens in the collection of the Department of Geology, University of Western Australia.

(iii) Garnet-biotite gneiss (25589),—These rocks occur as very fine-grained ($\frac{1}{4}$–$\frac{1}{2}$ mm.) lenses in the microcline and oligoclase gneisses. They have an equigranular granulitic texture developed in abundant grains of pink garnet (35 per cent.) and quartz (30 per cent). Their banded appearance is due to alignment of the flakes of brown biotite which form 15 per cent of the rock ; sericitised oligoclase makes up the remainder.

(iv) Graphite-bearing gneiss (24655),—The only specimen of this rock-type comes from the kaolinised zone near one of the central laterite mesas. Although the graphite remains unaltered, the original felspars and ferromagnesians have been converted to kaolinite minerals. Bands of these minerals alternate with thin quartz and graphite bands in which the graphite is in well-developed flakes $\frac{1}{2}$ mm. in diameter.

(v) Crush-Zone " Quartzites" (30029).—Certain highly-quartzose rocks occur in isolated outcrops which are not structurally related to the two bands of quartzite. They are not bedded and have a milky appearance caused by the fineness of the quartz grains. The quartz appeared either to have been crushed or to have crystallised under shearing conditions. The type specimen (30029), shows irregularly-shaped inclusions of gneiss amongst the fine-grained quartz ; so the rock must represent a crush-zone in the gneiss. A line of these lenses points to a possible major shear in one part of the area.

(b) *Pegmatites.*

(i) Microcline-biotite pegmatites.—In some places the gneiss is traversed by coarse-grained pegmatite dykes. Specimen (25558) contains crystals of microcline 3 inches long and books of biotite 1$\frac{1}{2}$ inches long set in a matrix of quartz. No accessory minerals are visible in this dyke whose dominant minerals belong to the same metamorphic facies as the enclosing gneiss.

Common throughout the area are finer-grained pegmatites in narrow veins 2 inches wide. These, containing grains of biotite, microcline, oligoclase and quartz up to 4 mm. in diameter, are found transgressing the gneiss (25553), and the metasediments (25561). Apparently the nature of the host rock affects the composition of the vein for (25561), traversing a chrome-muscovite quartzite, contains muscovite, oligoclase and quartz.

These pegmatites are pre-granite in age for they are displaced by the granite intrusions.

(ii) Quartz-pyrite vein (25570).—In the southern part of the Mt. Mackie area there occurs a coarse-grained quartz-pyrite vein. Cubic crystals of pyrite, with striated faces up to a square inch in area, are set in a groundmass of quartz. In the weathered outcrop, the pyrite has either been completely leached out or converted to limonite. The relationship of this vein to the gneiss, the granite, or the dolerites is uncertain, but it is probably connected with the pegmatites. The coarseness of grain size suggests that it was, like them, a locus of high ionic mobility.

(c) *Lenses in the Gneiss.*

Apart from the somewhat lenticular quartzite bands, there are also less regular lenses in the gneiss, which sometimes contain sedimentary banding ; structures developed in them are conformable with those in the quartzite bands. They include :—

(i) Metajaspilites.—These finely-banded metasediments are well developed in lenses throughout the gneiss (See under section IV, 2 : Metasedimentary Bands).

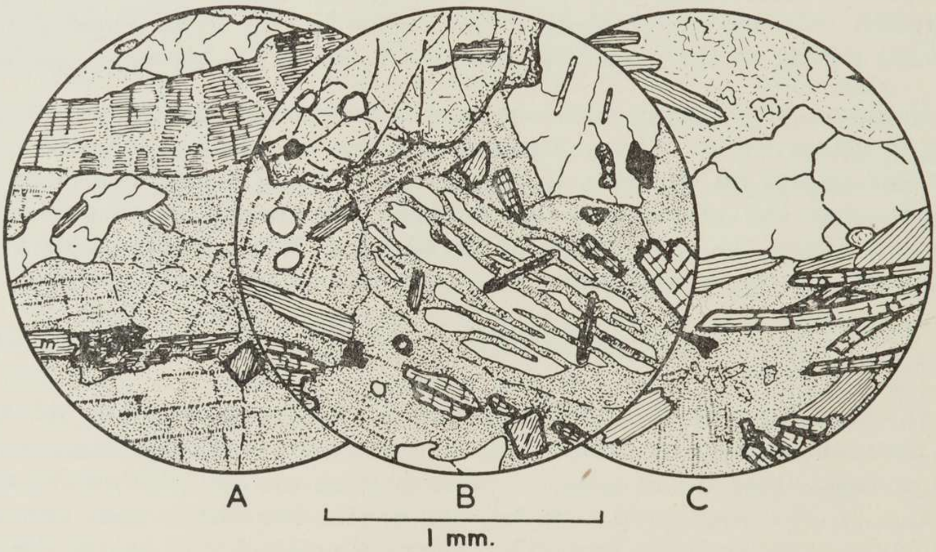
(ii) Hornblende granulites.—Containing small (1 mm.), equidimensional grains of hornblende, plagioclase and quartz, these typically sugary rocks show variations in colour from grey to black, depending on the percentage of hornblende present.

The hornblende commonly developed is strongly pleochroic with X yellow, Y deep olive green, Z deep green (Z>Y>X). Although most specimens show division into hornblende-rich and plagioclase-rich bands, in some only a preferred orientation of the prism cleavages of the hornblende crystals gives the rock its foliation.

The nature of the plagioclase varies, the most common being an andesine which may, or may not, be associated with quartz. Common accessories are magnetite and sphene. The type specimen (25554) contains andesine-labradorite, a blue hornblende (X light yellow-brown, Y deep olive green, Z deep blue (Y>Z>X)) and a diopsidic augite. A much more sodic phase is shown by (25579) which contains hornblende, an albite-oligoclase and quartz.

(iii) Garnet-biotite-sillimanite-cordierite-anthophyllite rocks represent basic lenses in the original sediments. They are dark grey to black in colour, due to the presence of biotite. The cordierite gives to the rocks its characteristic greasy appearance but most noticeable of all are large, pink garnets.

In thin section the latter sometimes appear as large, well-developed idioblasts containing poikiloblastic inclusions of quartz, cordierite, magnetite and biotite ; in other specimens are aggregates of irregularly shaped garnet crystals, separated by small crystals of quartz or cordierite.



Text Figure 2.

Garnet-biotite-sillimanite-cordierite-anthophyllite-rocks.

A. 25563. Anthophyllite-rich specimen. The anthophyllite is in stout laths with a well-developed cleavage; it is showing alteration to a fine, fibrous, orthorhombic mineral. Biotite (good cleavage), quartz (clear), and muscovite (m) are minor constituents. The groundmass is pinitised cordierite. A rhomb-shaped end-section of sillimanite occurs in the lower part of the field.

B. 25572. Variety with partially altered cordierite—a large crystal in the centre of the field shows partial alteration to pinite along cleavages. The cordierite contains poikiloblastic inclusions of cross-fractured prisms of sillimanite, together with quartz (clear), biotite (cleavage), zircon (rounded, high relief) and magnetite. The edge of a large garnet idioblast occurs at the top of the field.

C. 25385. Oligoclase-cordierite rock. Partially sericitised oligoclase (top) occurs with biotite, quartz, sillimanite (in cross-fractured needles with righ relief) and pinitised cordierite.

Quartz-rich and cordierite-rich layers produce a rough banding. The quartz occurs in long irregular stringers in a mass of cordierite. Embedded in the quartz are small needles of sillimanite (var. fibrolite) ; associated with both the cordierite and quartz are stout prisms of sillimanite, basal sections of which give (+) 2V = 26° (Text fig. 2B).

Cordierite, completely altered to a yellow-brown mass of brightly-polarising pinite (sericite mica), comprises nearly 40 per cent of most specimens. The cordierite contains most of the other minerals as poikiloblastic inclusions, notably flakes of brown biotite (X yellow, Y chestnut brown, Z deep chestnut brown), magnetite and rounded grains of quartz. In only one specimen (25572) is any recognisable amount of unaltered cordierite found ; its weakly-birefringent crystals showing hydration, along cleavage planes and other lines of weakness, to yellowish pinite (fig. 2B). A basal section of one crystal shows polysynthetic twinning in two planes set 60° apart.

Occasionally associated with the cordierite are large ($\frac{1}{2}$ mm. x $1\frac{1}{2}$ mm.) colourless prisms of an orthorhombic mineral with well developed prism cleavages—an anthophyllite. This mineral, which is often associated with muscovite, is partially, or sometimes wholly, altered to a fibrous orthorhombic mineral with low relief and high birefringence (text fig. 2A).

In the acid members of this type, the garnet does not develop ; instead, bands of quartz and oligoclase occur amongst the bands of cordierite and biotite. In (25385), the oligoclase is altered to a sericite, distinguished from the pinite by its grey colour and coarseness of grain (text fig. 2C). In the most acid member (25168), which is an oligoclase-biotite-cordierite gneiss, the oligoclase-quartz bands are more abundant than the basic bands and the oligoclase is only partly sericitised (as it is in the gneisses).

2. Metasedimentary Bands.

(a) *Schists.*

Mica schists are not abundant since they are easily weathered. Nevertheless, sands and cherts predominated over clayey rocks in the original succession.

(i) Garnet-sillimanite-muscovite schist.—Scattered outcrops of sillimanite-muscovite-quartz schist and garnet-muscovite-quartz schist occur in the bands of metasediments near the stretch-thrusts at (80N, 340W), in the western belt of metasediments, and near Mt. Mackie.

(ii) Kyanite-anthophyllite schist (25401). This specimen, from the western limb of the main fold, shows a marked parallelism of coarse crystals (up to 7 mm. long) of blue-green kyanite. These have an extinction angle of 30°, a well-developed prism cleavage, and an imperfect cross-parting. Bands of muscovite and kyanite, which form 50 per cent of the rock, alternate with quartzose bands containing colourless orthorhombic prisms of anthophyllite.

(b) *Quartzites.*

Most of the quartzites show a green colouration due to chrome-mica flakes. The percentage of mica varies considerably in the different lenses, from only a trace up to 20 per cent. or more, *e.g.*, (25379), which is strongly green in colour. The coarse-grained quartzites, although greenish in colour, show very little chrome-muscovite, none being seen in thin section.

(i) Felspathic quartzite (24661).—This is a coarsely crystalline rock comprised almost entirely of an interlocking mosaic of quartz grains up to 5 mm. in diameter. The only other mineral is microcline in rounded turbid grains—apparently a few detrital grains deposited in the otherwise pure sandstone from which this rock was formed. With admixtures of clay in the original sandstone, sillimanite needles formed within the quartz grains and the rock grades into the garnet-sillimanite quartzite group.

If subjected to shearing stress after recrystallation, these coarse-grained brittle rocks show marked cataclastic sturctures. One such (24651), found near the thrust-plane at Mt. Mackie shows the breakdown of a large quartz crystal into a fine micro-crystalline groundmass (Plate II (a)). Due to strain effects accompanying the shearing, the crystal shows marked undulose extinction.

(ii) Garnet-sillimanite quartzite (25411).—In this quartz-rich rock, the original bedding planes are now composed of a felted mass of needles of sillimanite (var. fibrolite). Small idioblastic garnets, up to 3 mm. in diameter, are abundant throughout.

Under the microscope, the sillimanite needles are seen to be embedded in an interlocking mosaic of quartz crystals. This type thus represents a transition from the pure quartzites with increasing alumina. A further increase of alumina produces the garnet-sillimanite-quartz schists found at Mt. Mackie. The garnets in this rock-type have been weathered out, leaving well-developed limonite boxwork structures.

(iii) Chrome-muscovite quartzite (25379).—This shows a marked development of green chrome-mica. Elongation of quartz grains and this mica on the bedding planes produces a marked *b*-lineation parallel to the *b*-tectonic axis. The rock was in a very plastic state when this lineation formed, for, in this specimen, the quartz grains have been drawn out into thin wisps parallel to *b* without showing undulose extinction or other signs of strain (Plate II b). The quartz grains are interbanded with flakes of a white mica which is altering to a fine-grained aggregate of pale green mica. This mica is comparable to that already described from Toodyay (Prider, 1944, p. 32). Needles of sillimanite and grains of zircon and rutile occur as inclusions in the quartz grains and in the mica. Both the sillimanite and the rutile are elongated parallel to *b*.

(c) *Metajaspilites.*

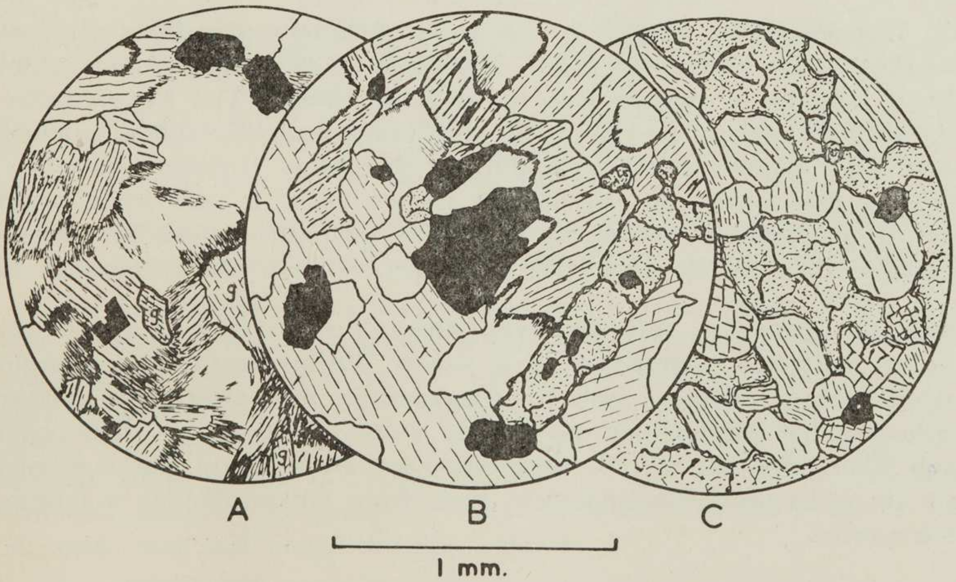
Because of their fine banding and numerous slump structures, these iron-rich rocks are considered to be metamorphosed cherts. Some types, however, represent recrystallised ferruginous sandstones and clayey ferruginous sandstones.

Near Hamersley Siding, the metajaspilites are found as numerous scattered lenses in the gneiss and as close associates of the quartzite bands into which they sometimes grade. They have their maximum development to the south-west of Mt. Mackie where a variety of types occurs. A thin veneer of iron-rich laterite, similar to the iron ore deposits at Clackline which yield 45.5 per cent of iron (McWhae, 1498, p. 72), has formed over the greater part of this mass of metajaspilite.

(i) Magnetite quartzite (25583).—The quartzites grade, both along and across the strike, into ferruginous quartzites which consist of alternating bands of coarse granular quartzite and bands made up of small (1 mm.) equidimensional grains of quartz and magnetite. Although quartz predominates in this rock-type, its division into marked quartzose and iron-rich bands indicates classification as a metajaspilite. This is supported by the presence in (25581), of small weathered grains of pyroxene, indicating a transitional phase between the magnetite quartzites and the garnet-hypersthene-magnetite-quartz granulites.

(ii) Garnet-hypersthene-magnetite-quartz granulites.—These rock-types are all characterised by a granoblastic texture and by relict sedimentary bedding, now shown by variations in the mineral content of neighbouring bands which vary in width from 1 mm. to 1 cm.

A variety of types is included in this group. Some are so rich in quartz that they may be called pyroxene quartzites ; in others quartz occurs in relatively few layers, the major part of the rocks being garnet hypersthenite. Magnetite and hypersthene are present in all examples, but the proportions of quartz and garnet are apparently inverse, the quartzose members being free of garnet while the garnet-rich members are almost completely free of quartz.



Text Figure 3.

Garnet-hypersthene-magnetite-quartz granulites.

A. 24662. A granoblastic aggregate of hyersthene (coarse cleavage), gunerite (g), magnetite (black) and quartz (clear). The grunerite and hypersthene grains show alteration, along their margins, to fibrous ferroanthophyllite.

B. 25404. The hypersthene (coarse cleavage) shows an alteration to ferroanthophyllite when in contact with quartz. Grunerite (fine cleavage) shows no reaction. Garnet (high relief) makes its appearance in the series. Magnetite is present.

C. 25448. A granoblastic aggregate of garnet (high relief) and hypersthene (cleavage). Magnetite (black) is accessory.

Since quartz forms 50 per cent of (24662), it could be called a hypersthene quartzite. It forms the link between the magnetite quartzites and the hypersthene-garnet granulites. Miles (1947 (a), p. 138) mentions a similar rock, containing also plagioclase and biotite, from the vicinity of Mt. Bakewell, York. Specimen (24662) contains bands of coarse crystals of quartz up to 5 mm. in diameter alternating with fine-grained (½ mm.) granulitic bands of quartz, magnetite and hypersthene (X yellow, Z pale green). Associated with the hypersthene are occasional grains of twinned highly birefringent grunerite (text fig. 3A). Both the hypersthene and the grunerite have reacted with the quartz to give fine needle-like crystals of ferroanthophyllite. Similar alteration of hypersthene to ferroanthophyllite was noted in meta-jaspilites from Bolgart (Miles, 1947 (a), p. 136). These fibres are oriented parallel to the crystals of hypersthene and grunerite, which they enclose, and appear to be formed at the expense of the major ferromagnesians.

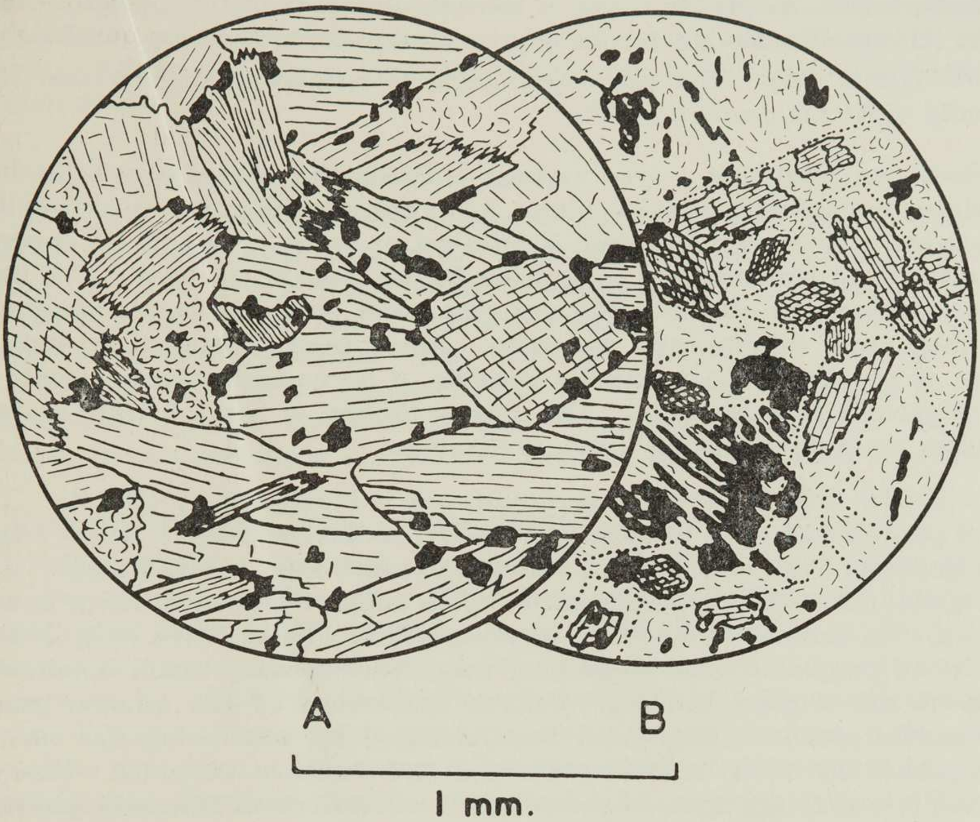
All stages between this quartzose type and the garnet-rich types are found. (25404) is an example of these intermediary rocks (text fig. 3B). It contains large crystals of grunerite and hypersthene in association with magnetite, quartz and pink garnet. The hypersthene shows the same fibrous alteration product as seen in (24662). Miles (1947, (a) p. 138) describes a similar rock-type from Bolgart, the fibres of which show variations in mineral type between ferroanthophyllite and a cummingtonite-grunerite.

A garnet-rich variant (25448), contains quartz in a few widely-scattered bands while the major part is a garnet hypersthenite (text fig. 3C). Bands of pure hypersthene granulite up to 8 mm. wide alternate with bands, 6 mm. wide, of garnet and hypersthene (X pinkish-yellow, Z green). Grunerite, a blue-green hornblende, and magnetite are present in small amounts in these garnetiferous bands.

(iii) Hypersthenite (25367).—The most striking rock from the meta-jaspilite area to the south-west of Mt. Mackie is (25367) which consists almost entirely of crystals of hypersthene up to 4 cm. long. The hypersthene (X yellowish pink, Z green) ; (—) 2V = 57° ± 3°) contains poikiloblastic inclusions of quartz and magnetite up to ½ mm. in diameter. Intergrown with the hypersthene, and sometimes containing inclusions of it, are small twinned crystals of grunerite. Associated with the grunerite crystals, occasional patches of a blue-green hornblende with very strong absorption are seen.

Both the grunerite and the hypersthene are altering along planes of fracture to radiating aggregates of a yellow fibrous amphibole, associated with which are granules of secondary magnetite, now altering to hematite. The orthorhombic habit of the amphibole shows it to be a ferroanthophyllite, although Miles (1947 (a), p. 139) determined a similar yellow fibrous alteration product (in a hypersthene-magnetite rock from Greenhills) as a cummingtonite-grunerite.

(iv) Cummingtonite-magnetite granulite (25576).—Fine grains of magnetite (to ⅛ mm. in diameter) form a rudimentary banding in these otherwise poorly bedded rocks. The magnetite is set in a granular aggregate of pale green prisms of cummingtonite which show an attempt at a preferred orientation (Text fig. 4A). This rock-type is easily distinguished from the other meta-jaspilites by its pale green colour and soft soapy " feel," due to properties peculiar to the cummingtonite and its weathering products. The cummingtonite, which forms prisms up to 2 mm. in length, has the following properties : X colourless, Y pale olive, Z very pale green ; $Y > Z > X$; $Z \wedge c = 9° \pm 2°$; (+) 2 V = 82° ± 4°. The mineral is not a true cummingtonite for one 110 cleavage shows a better development than the other and *c* lies 3° off the optic plane ; this mineral is triclinic.



Text Figure 4.

Cummingtonite-magnetite granulite.

A. "Normal" rock—a granoblastic aggregate of prisms of pale green cummingtonite (cleavage), altering in places to chlorite (irregular flakes). Magnetite (black), in small grains, is scattered throughout the rock.

B. 25388. Highly altered rock. Only a few relicts (showing cleavage) of the original cummingtonite crystals (outlines dotted) remain in a groundmass of talc and chlorite (irregular flakes) with primary and secondary magnetite.

A metajaspilite, from the Malkup Area, containing cummingtonite associated with a blue-green hornblende was described by Cole and Gloe (1940).

There is a marked variation in the degree of alteration of the cummingtonite. The type specimen shows a partial alteration to pale green chlorite. In (25578) and (30025) the chlorite is joined by a highly birefringent talc as a second decomposition product. (25388) consists almost entirely of colourless chlorite, talc and primary and secondary magnetite. In this specimen, alteration has proceeded almost to completion, only a few scattered, partially decomposed cores of cummingtonite crystals remain in the midst of a jumble of chlorite, talc and magnetite (text fig. 4).

A variant of this rock-type is found in (25369) where a pale green hornblende (X colourless, Y olive green, Z pale green) is associated with the cummingtonite, chlorite and magnetite.

(v) Grunerite metajaspilites.—Specimen (25397) shows the excellent sedimentary banding characteristic of the metajaspilites. It is divided into bands 4 mm. wide, containing two amphiboles, and 3 mm. wide bands of quartz. The amphiboles are grunerite and a blue-green hornblende with a very strong absorption. The nature of this hornblende, the intense colour of which is due to its high iron content, was discussed by Miles (1943, p. 36). He mentioned its occurrence in crystals which are in optical continuity with grunerite. In both this specimen (25397), and in (25440), crystals of grunerite contain patches of the hornblende in optical continuity with the grunerite. The grunerite, which, in places, shows a brownish-black turbidity, due to alteration to (?) hematite, has the following properties :—$Z \wedge c = 16°$, (—) $2V = 84°$, $110 \wedge 1\bar{1}0 = 55\frac{1}{2}°$ The extinction angle is noticeably higher than that normally cited for grunerite (11°).

Specimen (25402) is a type midway between the grunerite metajaspilite and the cummingtonite metajaspilite. As in the cummingtonite metajaspilite, the original sedimentary banding is retained in bands of magnetite crystals, now altering to hematite and comprising 20 per cent. of the rock. The blue-green hornblende is abundant (15 per cent.) and occurs in bands associated with magnetite, chlorite, and hematite. Apart from occasional crystals of quartz (5 per cent.), the remainder consists of an equigranular aggregate of cummingtonite and grunerite. The overall texture is that of a fine-grained granulite, no grain exceeding ½ mm. in diameter.

A totally different type of grunerite rock is illustrated by (30024). The closest parallel rock-type to (30024) is the hypersthenite (25367), which comes from the same large metajaspilite lens to the south-west of Mt. Mackie. The rock contained large crystals, 6 cm. or more long, of grunerite which is now altering to a mass of fibres of ferroanthophyllite. These fibres radiate from a series of parallel cracks, containing magnetite crystals, which apparently represent the original bedding. Only a few relicts of the original grains of grunerite remain. They have been bleached by weathering but can be distinguished by their inclined extinction and multiple twinning. Most of the rock is now an aggregate of yellow to colourless fibres of ferroanthophyllite. Here and there are seen flakes of yellow-brown biotite.

(vi) Grunerite-hypersthene metajaspilite (25440).—Alternating throughout this rock are two distinct types of bands each 1 cm. wide. One contains coarse crystals of black amphibole and quartz, the other consists mainly of silky-lustred fibres of a dark green amphibole arranged with their long axes at right angles to the banding. Within the latter bands are layers of magnetite crystals and fine grains of amphibole paralleling the main banding. Associated with the magnetite bands are grains of rutile and apatite.

On microscopic examination the fibrous layers are seen to be composed of a very fine aggregate of pale needles of grunerite ($X = Y$ colourless, Z very pale green). Occurring amongst the fibrous mass are bands of granular crystals of twinned grunerite, averaging ½ mm. in diameter. Some of these crystals are in optical continuity with crystals of the blue-green hornblende. Near the margin of one of these fibrous areas, two large crystals, cored by blue-green hornblende, show irregular alteration to pale-coloured grunerite along their margins.

The intervening bands consist of quartzose granulite in which crystals attain 3 mm. in diameter. The main mineral developed in this band is a turbid amphibole with two well-developed, but unequally developed, cleavages. One cleavage is perfectly formed, its cleavage planes being very closely spaced, imparting to the mineral the appearance of diallage. Set about midway between the two cleavages is a plane of multiple twinning. This twinning is also visible on sections in which the cleavage does not show. The twinning and high birefringence of this amphibole point to grunerite, whereas the unequally developed cleavages and the positive optical character, as shown in some sections, indicates a triclinic " cummingtonite."

Associated with this mineral are crystals of the blue-green hornblende and a hypersthene (X yellow to colourless, Z green) which is notable for a well-developed multiple twinning parallel to the optic plane. The grunerite, hypersthene and hornblende when in contact with grains of quartz, show alteration to fine needles of ferroanthophyllite as in the garnet-hypersthene metajaspilites.

3. Granites.

A large boss of homogeneous equigranular fine-grained granite outcrops in the central-western part of the area. Elsewhere the granite is found in dykes, ranging from 1 inch to 10 feet or more in width, traversing the gneiss and its associated quartz veins and pegmatite dykes. The granite is therefore younger than the pegmatites. The intrusive relationships of these rocks are seen in Plate III (b). The granites in the dykes and in the boss are grey coloured acid rocks in which biotite does not exceed 10 per cent. In some dykes the biotite content is so small that the rock might be called an aplite.

(a) *Microcline-oligoclase-biotite granite* (25551).

(25551) contains microcline, oligoclase, biotite and quartz in grains averaging ½ mm. in diameter. Microcline, which is the most abundant mineral, is in clear, unaltered grains, some of which contain small rounded inclusions of quartz. The oligoclase (Ab_8 An_2) has a turbid appearance due to alteration to white, highly birefringent sericite. In some specimens well-developed flakes of muscovite, growing parallel to the cleavage of the oligoclase, have developed. The reason for this unusual alteration product of the oligoclase was discussed earlier. Reaction with neighbouring crystals of microcline has produced myrmekitic blebs of quartz in some crystals of oligoclase. Quartz and brown biotite, which is altering to a greenish chlorite, are the other constituents.

(b) *Porphyritic microcline granite.*

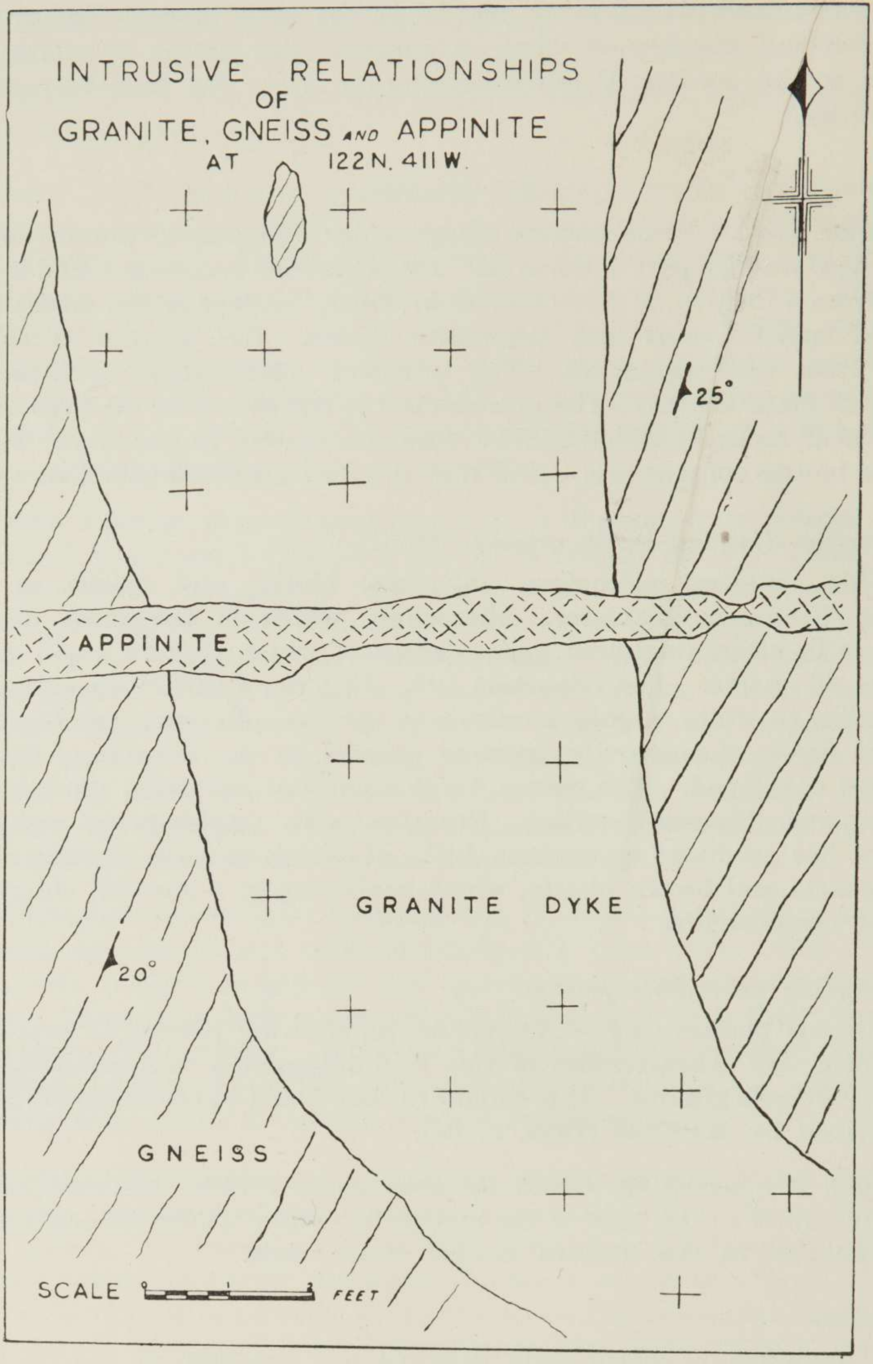
Numerous phenocrysts of microcline, all showing perfect or near-perfect crystal form, are characteristic of this medium-grained microcline-oligoclase-biotite-hornblende granite. It is similar to that found to the south of Clackline and described by McWhae (1948, p. 66).

Though not occurring within the area under review this rock has been noted three miles to the west of the metasedimentary bands, its contact being roughly parallel to the western border of the area.

(c) *Appinites.*

The appinites or hornblende granites are fine-grained, grey-coloured, intermediate rocks which occur as dykes or irregular shaped patches in the granite and gneiss. Two distinct rock-types, whose chemical compositions are probably indentical, fall into this group. The most common type contains microcline, hornblende, chlorite, oligoclase and sometimes quartz ; the other contains chloritised biotite, oligoclase and quartz. Although having the form of xenoliths in the gneiss, these occurrences are noted for their very sharp contacts. In some outcrops, notably one at the waterfall in Cobham Brook, the edges of the dykes are marked by partially resorbed oligoclase crystals identical with those in the surrounding gneiss.

At a small waterfall 122 chains north, and 411 chains west of datum, a narrow dyke of biotite-oligoclase appinite traverses both the gneiss and a granite dyke (text fig. 5). From this it would appear that the appinites are younger than both the gneiss and the fine-grained granite (the " younger granite ").

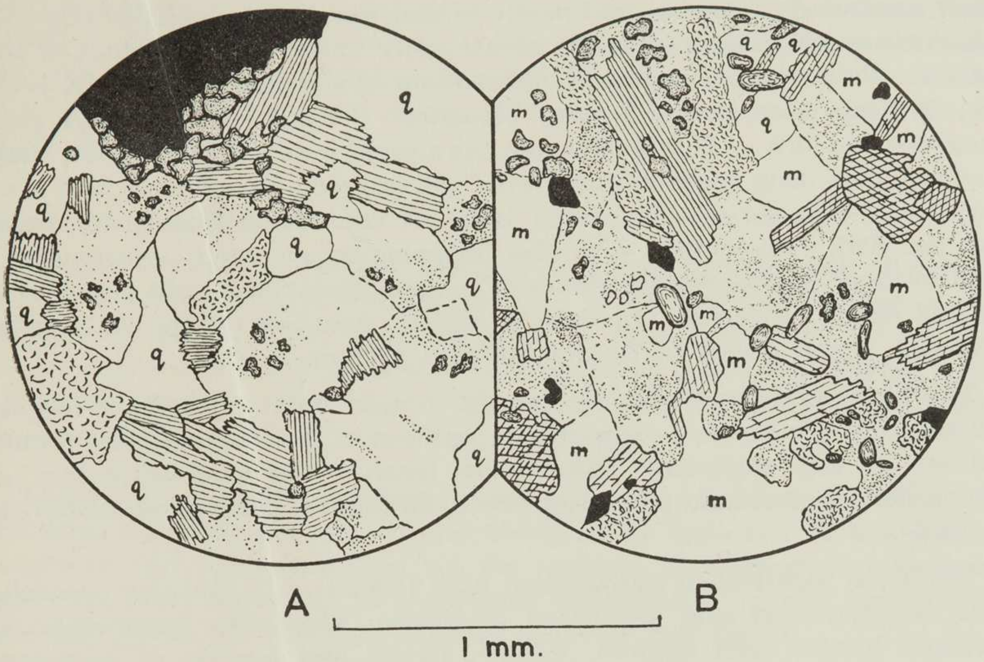


Text Figure 5.

Geological sketch map at 122 N. 411 W.

The occurrence of these hornblende granites in the Western Australian Pre-Cambrian has been known for some time, although their relationship to the other igneous rocks was obscure. One of the earliest records of this rock-type is found on a map of the Muresk area by Prof. E. de C. Clarke and Messrs. F. G. Forman and A. B. Adams (1927). Several bands of hornblende granite, paralleling the structure in the surrounding gneiss, are shown. Examination of a specimen (7262), from one of these bands showed it to be the hornblende-microcline appinite.

The biotite-oligoclase variety of appinite was noted, in the Toodyay area, by Prider (1944, pp. 112–3). The rocks are described as " irregular-shaped, elongated, darker-coloured, patches, in which the foliation approximates to that in the surrounding gneiss." The sharp boundaries of these "xenoliths," with complete absence of any transitional zone, is characteristic of this rock-type.



Text Figure 6.

Appinites.

A. 25376. Biotite-oligoclase appinite. Clots of biotite flakes (with cleavage), now completely altered to chlorite, occur in a granoblastic aggregate of quartz (q) and oligoclase (partly saussuritised). Patches of chlorite (irregular flakes) are associated with the biotite. Occasional large crystals of pyrite (black) rimmed with granular epidote are found.

B. 30030. Microcline-hornblende--oligoclase appinite. Hornblende, in dark green prisms (imperfect cleavage), associated with chlorite, epidote (high relief, irregular grains) and sphene (high relief, rounded grains) is the main ferromagnesian. A crystal of chloritised biotite appears in the upper left of the field. The felspars are unaltered microcline (m) and saussuritised oligoclase. Quartz (q) and pyrite are present.

(i) Biotite-oligoclase appinite (25376).—This specimen, from the type-locality at (122N, 411W), contains oligoclase (40 per cent), chloritised biotite (30 per cent), quartz (20 per cent), with pyrite and epidote comprising the remainder. The thick books of completely chloritised biotite, from $\frac{3}{4}$ to 2 mm. in length, collect in basic clots, 3 mm. or more in diameter— a feature common to both varieties of appinite. Between these basic areas, an equigranular, equidimensional aggregate of quartz and slightly saussuritised and sericitised oligoclase occurs (text fig 6A). Large crystals of pyrite are sparsely scattered throughout the rock. Some of these are surrounded by a rim of granules of epidote. Elsewhere, epidote is associated with the clots of biotite and occurs as the product of saussuritisation of the oligoclase.

In mineral content this specimen resembles (25602) from the waterfall in Cobham Brook. (25602) is very fine-grained ($\frac{1}{16}$ to $\frac{1}{8}$ mm. in diameter) containing quartz, magnetite, oligoclase (Ab_{83} An_{17}) and a brown biotite (X yellow, Z deep brown). The biotite, which does not show alteration to chlorite, is in thin flakes $\frac{3}{4}$ mm. long. These have a decussate arrangement in the centre of the dyke, but, near the margins, become aligned parallel to the contacts of the dyke.

(ii) Hornblende-microcline-oligoclase appinite (30030).—About 30 feet from the type-locality of the biotite-oligoclase appinite, a dyke of hornblende appinite, several feet wide, occurs. Specimen (30030) was collected from this dyke. It contains 60 per cent of an equidimensional equigranular aggregate of clear, unaltered microcline and partly saussuritised and sericitised oligoclase. Myrmekitic reaction structures are occasionally found at the contact of these minerals. Prisms of a blue-green hornblende with strong absorption (X yellow-green, Y deep olive green, Z deep blue-green ; Y > Z > X) occur in groups throughout the rock. This hornblende has altered in places to irregular shaped aggregates of a deep green chlorite with yellow-green pleochroism and strong absorption. Occasional well-formed laths of chloritised biotite are present (Text fig. 6B). Associated with the ferromagnesians, and occasionally included in them, are rounded granules of sphene, irregular shaped grains of epidote and cubes of pyrite. Epidote is also an associate of the saussuritised oligoclase. Small grains of quartz are also present.

The hornblende appinites frequently contain relict crystals of felspar—residuals from the gneiss ; occasionally, patches of granitic material occur as xenoliths in the appinite. Throughout these rocks saussuritisation and epidotisation are common processes, one dyke (25574) containing visible clots of epidote.

(30031) is identical in composition with (30030). It contains microcline, quartz, saussuritised and sericitised oligoclase, blue-green hornblende and chloritised biotite with epidote, sphene, pyrite and apatite as accessories. It comes from the fine-grained granite boss in the central western part of the area, where the appinite occurs in irregular shaped, grey-coloured patches in the granite. Although their contact with the granite is sharp, these patches have the appearance of xenoliths rather than bodily injections. Along the banks of Heale Brook several exposures of granite show bands of appinite lying parallel to the strike of the adjacent metasediments. Some of the appinites may possibly represent recrystallised basic bands in an originally gneissic terrain. But whatever the origin of the irregular shaped patches in the granite, the dykes traversing both granite and gneiss must have a similar genesis.

(30031) also contains scattered yellow-brown blebs of quartz. These are composed of a coarse interlocking mosaic of quartz grains which are partially digested by the appinite ; crystals of biotite are prising the quartz crystals apart. Nearby the granite has partially absorbed a band of chrome-muscovite quartzite (120) N, 394 W.)

Table 1.

Chemical analysis of appinite (30030).

		Norm.	
SiO_2	53·02		
Al_2O_3	18·68	or	21·68
FeO	3·98	ab	30·39
Fe_2O_3	3·09	an	23·91
TiO_2	1·12		
MnO	·14	di	7·60
CaO	7·56	hy	6·05
MgO	3·09	ol	0·93
K_2O	3·68		
Na_2O	3·62	mg	4·41
H_2O—105°C.	·10	il	2·13
H_2O+105°C.	·97	ap	1·68
CO_2	*Nil*		
P_2O_5	·71	Classification II, 5, 3, 3 (4).	
	99·76		

Analyst.—W. H. Herdsman.

This slightly undersaturated rock shows chemical affinities with the dolerites and shoshonites of the shoshonase group in the C.I.P.W. classification.

4. Younger Basic Intrusives.

All the rocks described above are traversed by quartz dolerite dykes, injected into two sets of tension fractures trending N.N.W.–S.S.E. and E.N.E.–W.S.W. respectively. Minor dykes, in the centre of the area, have a N.W.–S.E. trend. The majority are relatively fine-grained, much-epidotised dolerites; others are coarse-grained acid gabbroidal dolerites ; a third intermediate variety contains phenocrystal laths of saussuritised plagioclase averaging 5 mm. x 1 mm.

(a) *Quartz dolerite* (24669).

This is a typical dolerite consisting of an ophitic intergrowth of partially saussuritised basic andesine with augite ((+) 2V = 45° approx.) and a green hornblende (X pale yellow, Y yellow-green, Z pale olive green ; $Z > Y > X$). Both the augite and hornblende show alteration to pale green fibrous uralite and greenish chlorite. Quartz and skeletal crystals of pyrite each comprise 5 per cent of the rock. Apatite is an accessory.

The large dyke, which has been traced over a length of more than 4 miles in the area mapped, belongs to this fine-grained type but it has been so saussuritised and epidotised that all the original plagioclase and ferromagnesians have been converted to a granular aggregate of epidote and chlorite. Quartz and pyrite are the only original minerals still intact.

(b) *Porphyritic dolerite* (24672).

Laths of highly saussuritised plagioclase, probably an andesine or labradorite form the greater part of this specimen. Scattered amongst these laths are large (2 mm. diameter) crystals of augite ((+) 2V = 45°) which show alteration to chlorite and sometimes to uralite. Associated with the augite are skeletal crystals of pyrite. Apatite is an accessory.

(c) *Quartz gabbro* (25395).

In the hand-specimen this rock has a coarse-grained gabbroidal appearance. The coarseness of grain is constant throughout the dyke, no diminution in grain size due to chilling at the margins being noted. Specimens from narrow dykes show the same coarse texture as those from dykes three or four times their width. This apparent paradox can be explained if this quartz gabbro magma was a hot, volatile end-phase injection ; temperature effects on crystal size would then be reduced to a minimum ; volatility would be the controlling factor. That this intrusion is such is indicated by the abundance of quartz and oligoclase and the presence of brown hornblende. The coarseness of texture of this rock-type is partly illusory, for, although the grain size is larger than that of the quartz dolerites, the segregation of the ferromagnesians into clots gives the rock an exaggerated coarse-grained appearance.

The rock consist of a sub-ophitic intergrowth of highly saussuritised oligoclase (Ab_{77} An_{23}), and quartz with several ferromagnesians. The primary ferromagnesians are a neutral coloured augite ((+) 2V = 45°) and a brown hornblende (X yellow-brown, Y brownish olive green, Z very dark brown ; $Z > Y > X$). Both the augite and hornblende are altering to uralite in crystalline and fibrous form. Crystals of augite have developed a " reaction rim " of chlorite in pleochroic (yellow-green) flakes. Epidote is a common alteration product. Skeletal crystals of pyrite and needles of apatite are the accessories.

5. Laterite.

The laterite, which is formed over granitic and gneissic rocks, is a strongly cemented pisolitic type. The pisolites contain a concentrically banded deep red-brown core with a paler exterior and are held together by a light yellow-brown ferruginous cement. Small angular quartz grains occur throughout the pisolites and matrix.

6. Quaternary Arkose. (30032)

A coarse-grained, gritty, arkosic sandstone occurs in a creek bed near (125 N, 339 W). It contains angular grains of quartz, 3 mm. in diameter, together with a partially kaolinised felspar and small angular chips of gneiss. Small, rounded, black grains of ferromagnesians are sparsely scattered throughout. The rock, which is, in places, well cemented and coherent, has a clay matrix no doubt derived from the kaolinised zone at the head of the stream.

Current bedding in this deposit indicates that it was probably laid down in a small, shallow, lake formed by some local interference with the water-table. This disturbance apparently affected a large area adjacent to Hamersley Siding, for the 1927 map of Muresk (Clarke, Forman, and Adams) shows a considerable deposit of an identical rock, specimen (7261), in the valley of Hughes Brook.

B. FLUORESCENCE TESTS.

Under the guidance of Mr. A. F. Wilson, the gneissic and granitic rocks were subjected to fluorescence tests with a short-wavelength ultra-violet lamp. The granitic suite near Hamersley is notably poor in accessory minerals, so, as expected, no important fluorescence of zircon or apatite was found. The felspars only were used in these tests.

It has been found (Wilson, 1950) that crystals of potash felspar, and sometimes plagioclases, when crystallised from an actual granite magma, or when formed by felspathisation, often exhibit a rose-pink fluorescence. If it can be established that the felspars of the original terrain do not fluoresce, then the process of felspathisation can be followed, by using the felspars as markers. The felspars of very fine-grained acid rocks, even if of magmatic origin, do not fluoresce.

The felspars of the gneiss from the central and eastern parts of the Hamersley Area showed no reaction to ultra-violet light. It is thus interpreted as being a recrystallisation *in situ* of a felspathic sediment—an arkose. The gneiss is not of magmatic origin, neither has it been subjected to felspathisation.

Near the margin of the massive granite, the gneiss contains crystals of fluorescent microcline. Here, apparently, the recrystallised arkose has received small additions of microcline from the adjacent granite mass. Specimen (25552) was one of those tested. It was found that occasional grains of microcline in the groundmass fluoresced, the microcline porphyroblasts being non-reactive. In this type of gneiss, therefore, although the rock has undergone felspathisation the materials of the porphyroblasts are native to the metasediment, not introduced.

Both the massive granite and its associated medium-grained dykes contain brightly fluorescing felspar, confirming their magmatic, or at least felspathised origin. The fine-grained granite dykes do not show fluorescing felspars. All the specimens of appinite showed a bright pink fluorescence of their felspars. They are, therefore, interpreted as of magmatic origin, probably related to the granites.

C. PETROGENESIS.

1. Gneisses.

This hybrid complex contains a uniformly-banded medium-grained type, a coarse-grained porphyroblastic type, and a fine-grained well-banded type showing all the characteristics of a metasedimentary gneiss.

Prider (1944, p. 107) considers that the gneisses of the Toodyay Area are magmatic intrusions. He bases this concept on (i) the quartz grains lack preferred orientation and show no signs of strain, (ii) the gneiss contains xenoliths of metasediments and (iii) occasional discordant contacts are seen between the gneiss and the quartzite.

McWhae (1948, p. 65) suggests that the gneiss in the Lawnswood Area was introduced as " a highly viscous magma during the period of diastrophism." However, he found a hybrid granitic gneiss which he considers to be the result of granitisation of the basic lenses in the gneiss.

The gneiss at Hamersley is thought to be, not a magmatic intrusion, nor, in most places, a product of felspathisation, but a recrystallisation of an arkosic sediment under conditions of regional metamorphism. It seems very improbable that such a delicate structure as that shown on Plate I, could have withstood any degree of mobilisation in the gneiss, much less a bodily injection of a viscous magma without suffering severe dislocation or being totally destroyed.

Where strike and dip readings can be obtained, the foliation in the gneiss closely parallels the contortions of the metasedimentary bands thus emphasising their conformable relationship.

The presence of graphite in the gneiss at (37N, 270W) points to a sedimentary origin and indicates the probability that organic life existed in the seas in which these rocks were deposited. The fluorescence tests also indicate a sedimentary origin.

The high percentage of microcline and the pronounced sericitisation of the oligoclase in most specimens indicates that the parent rock was probably over-saturated with potash, probably a potassic arkose. The presence of the low temperature ($< 600°C$) felspar, microcline, also indicates that the gneiss is a recrystallisation, *in situ*, of arkose, rather than a magmatic injection. Fluorescent tests show that the large microcline porphyroblasts in (25552) were not introduced by felspathisation but were developed from the original sediment because of its high potash content.

As noted by Ramberg (1949), the minerals developed in the pegmatites—microcline, oligoclase, biotite, and quartz—are identical with those in the surrounding gneiss. These minerals are characteristic of a relatively low temperature of formation. Hence the pegmatites do not necessarily represent minerals deposited from hot volatile magmatic fluids ; rather they may represent zones in the gneiss where pressure-temperature-composition conditions were such that ionic diffusion could take place rapidly, thus enabling large crystals to form. The pegmatites are, therefore, interpreted as local variants in the gneiss and not bodily injections into it.

Near the edge of the granite mass in the west of the area the gneiss shows partial felspathisation, apparently caused by emanations from the granite. From the structure section (Plate I) it appears that, during its emplacement, the granite assimilated, rather than forced aside, the metasediments—this is evidenced by a quartzite xenolith in the granite mass. The granite may thus have been emplaced by the " soaking up " of the pre-existing gneiss and metasediments by the emanations from the west, rather than bodily injection of a plutonic magma. The granite may this be interpreted, in part at least, as a mobilisation of the pre-existing terrain. This mobilised phase was " injected " into the gneiss in the form of dykes which occur throughout the area, some being noted as far east as Mt. Mackie.

Associated with the granitic rocks are appinite dykes, the felspars of which show a pink fluorescence. Thus they may be interpreted as magmatic rocks, or at least as mobilised rocks, probably closely related to the massive granite. The chemical analysis of one of these appinites shows a similarity to analyses of rocks of a doleritic nature. Their dyke-like occurrence indicates that the appinites may be an associate of the quartz dolerite suite. However the appinites are undersaturated rocks whereas the dolerites are saturated. The irregularly-shaped patches of appinite in the massive granite to the west of the area possibly formed either from basic emanations which replaced the granite or by recrystallisation of basic lenses in the granite. Recrystallisation of basic lenses in an originally gneissic terrain seems an adequate explanation of the xenolithic bodies in the massive granite but it is inadequate to explain the " intrusive " dykes. Probably both the " xenoliths " and the " dykes " could be explained as the products of preferred replacement of country rock by basic emanations. Too little is known of the chemical compositions, modes of occurrence, and regional distribution, of the two types of appinite to make a definite statement of their origin at this juncture.

2. Quartzites and associated metasediments.

The quartzites, mica schists, cordierite-anthophyllite rocks, metajaspilites, etc., may now be considered as original lenses of differing facies in a basin of thick predominantly arkosic sedimentation. In such thick arkosic formations it is usual to find scattered lenses of such varied rocks as limestones, cherts and sandstones disturbing the uniformity of the main rock-type.

(a) *Hornblende granulites.*

The lenses of hornblende granulites are generally found near the main quartzite bands but are by no means abundant. As evidenced by their basic plagioclases and high percentage of hornblende, they are rich in calcium and probably are metamorphosed impure limestones, although Prider (1944, p. 121) considers them to be meta-basic igneous rocks.

(b) *Cordierite-anthophyllite rocks.*

With admixtures of clayey materials, the original arkose developed lenses of varying basicity. During metamorphism these were transformed into schistose and basic lenses, depending on the nature of their clay content. Thus the basic clay lenses gave rise to the garnet-biotite-sillimanite-cordierite-anthophyllite rocks. The sedimentary origin of these rocks is shown by their division, by no means perfect, into quartzose and cordierite-rich bands. The variations in the rock-type reflect variations in the original sediments ; the more basic the original clay, the richer the resultant rock in cordierite, biotite and garnet. Thus (25168) contained so little basic clay that garnet did not form, and only thin bands of cordierite, sillimanite and biotite have formed in an otherwise normal oligoclase gneiss. This rock thus shows an intermediary development between the oligoclase gneisses and the cordierite-anthophyllite lenses.

(c) *Garnet-sillimanite schists.*

Associated with the main quartzite bands are sillimanite-muscovite and garnet-muscovite schists. Occasional lenses of schists also occur in the gneiss. The maximum development of sillimanite is found in ares of greatest deformation in the fold—at (80N., 340W.) (*see* text fig. 10) and at Mt. Mackie. Along the western limb of the fold, where a directed pressure is attained by the sliding of beds one over the other, a kyanite-anthophyllite-muscovite schist formed from the original pelitic sediments.

(d) *Quartzites.*

The quartzites show marked variations in mineral content. Lenses that were initially very pure sandstones have recrystallised as interlocking mosaics of large quartz crystals. These sandstones occasionally carried a few grains of microcline derived from the neighbouring arkosic facies of sedimentation. On metamorphism these grains remained as small (½ mm.) rounded crystals in the quartzite mosaic.

Minor quantities of aluminous material in the original sediment now appear in the quartzites as inclusions of sillimanite within the quarsz crystalls. As the clay content of the sediment increased, with admixtures of basic material, the resultant metamorphic derivative tends towards the garnet-sillimanite quartzite group. The garnet-sillimanite layers represent former clay bands in the rock. With a further increase in clay content the resultant rocks become garnet-sillimanite schists. The garnet-sillimanite-quartz schists are the main schistose rock-types found at Mt. Mackie (*see* text fig. 9).

As a result of metamorphism clayey sandstones, containing a little chromic oxide, have changed into quartzites containing sillimanite and the green chrome muscovite so characteristic of the quartzites of the Jimperding Series.

The quartzites have recrystallised as coarse-grained granoblastic rocks in which the individual crystals are firmly intergrown. However, in an area where the metamorphic processes were accompanied by large-scale molecular rearrangement, as evidenced by the coarse grain size developed in the gneiss, it does not seem necessary to postulate high temperature recrystallisation to explain their coarseness of grain. Rather, moderate temperatures aided by free and rapid molecular interchange between adjoining crystals, would account for both the large grain size and the plastic flowage of the quartz grains. However, sillimanite is present in these rocks and this indicates that these rocks have been subjected to high grade regional metamorphism.

(e) *Metajaspilites.*

The final important group of the metasediments is the metajaspilites. These range from magnetite quartzites to pure amphibole rocks.

The magnetite quartzites are well banded rocks which, from their close association with the massive quartzites, probably represent metamorphosed ferruginous sandstones.

The garnet-hypersthene-magnetite-quartz granulites, with their fine banding and intricate slump structures, represent ferruginous cherts which received varying additions of basic clays and subsequently suffered metamorphism. Here we have an enigma ; hypersthene, a characteristically " dry " mineral, is found in metajaspilites which are associated with gneisses and schists containing " wet " minerals—biotite, chlorite and muscovite. However, in basic metamorphic rocks containing free quartz, hypersthene is the stable ferromagnesian. Any water present in the original chert would be absorbed during metamorphism, by the formation of grunerite or, in some instances, of ferroanthophyllite.

In the complex metajaspilite lens to the south-west of Mt. Mackie, several coarse-grained rocks occur ; (25367) and (30024) contain large crystals of hypersthene and grunerite respectively. These rocks probably represent " dry " and " wet " portions of a ferruginous chert in which the silica was just sufficient to satisfy the other oxides. The small quantity of water in the hypersthenite was taken up in the form of grunerite. The ferroanthophyllite in both rocks represents post-metamorphic decomposition.

Variations in the composition of the original sediments are reflected in the marked diversity of minerals developed during metamorphism. Slight variations in chemical composition produce hypersthene-grunerite, grunerite-hornblende, grunerite-cummingtonite or pure cummingtonite rocks. The latter are particularly unstable and rapidly alter to an aggregate of talc and chlorite.

The metajaspilites are considered, by some geologists, to be metamorphosed sideritic and greenalitic cherts (Miles, 1947 (a)). The accepted origin of such rocks involves slow deposition in epi-continental basins, in which mechanical sediments are rare. Such basins are found at the margins of almost peneplaned land-masses. One would not expect to find these slowly accumulating deposits in a basin of rapid sedimentation where the predominant deposit was arkose—the product of rapid mechanical weathering of a youthful continent.

After prolonged study of the Soft Iron Ores (an oxidised form of the metamorphosed iron formation) of the Lake Superior Region, Tyler (1949, p. 1107) has concluded that not all the metamorphosed iron formations were originally rich in iron. He considers that they originally consisted of ferruginous cherts or sideritic cherts, in which the iron content was not very high, but was, nevertheless, higher than that of the surrounding sediments. On metamorphism, iron-rich solutions or emanations circulated through the rocks. The iron-bearing cherts were the loci for additional deposition of iron resulting in the formation of iron silicate minerals (grunerite, stilpnomelane and minnesotaite). The emanations enriched the cherts in iron content. Slightly ferruginous cherts, which do not require such specialised conditions of deposition as do the iron-rich types, may be so enriched in iron by emanations during metamorphism, that they become iron ores.

Miles (1947 (b)), came to a similar conclusion regarding the Western Australian metajaspilites. He cites evidence of jaspilites, within a zone of granitisation, being leached to a white cherty quartzite, whilst the metajaspilites outside the granitised zone, were enriched in iron silicates and magnetite. With this evidence before us, it is possible that the metajaspilites at Hamersley were not necessarily very rich in iron when originally deposited. In the ionic reshuffling which accompanied the metamorphism and partial felspathisation of the gneiss, the jaspilite bands acted as loci for considerable accumulations of iron, magnesium and other elements. Variations in the composition of these ferromagnesian emanations from the gneiss are, in part, considered to be responsible for the varied types of metajaspilites in the area.

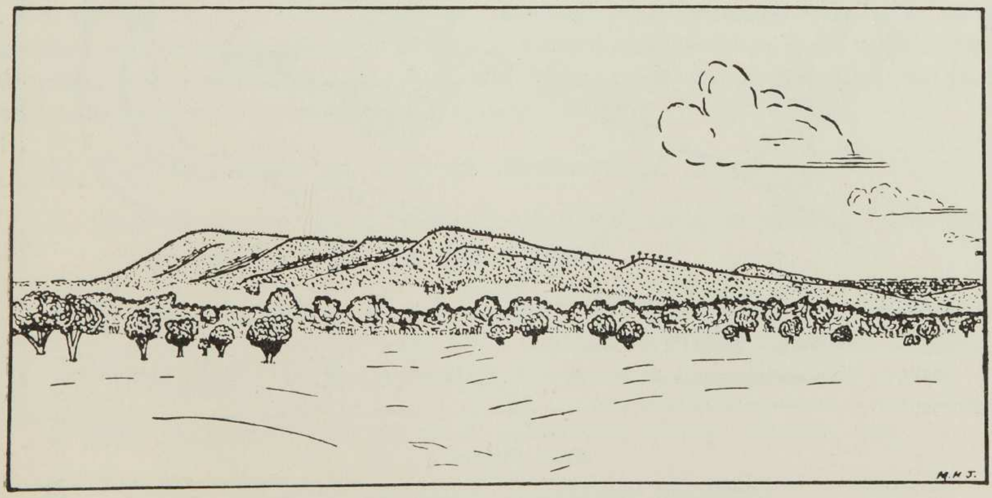
3. Quartz dolerites.

The latest intrusions are the quartz dolerites. The genesis of these rocks was discussed jointly with their petrography.

V. GEOLOGICAL STRUCTURE.

Major Structures.

The major structure in the area is a box-fold type of anticline whose axis strikes N.N.W.-S.S.E. ; it is overturned towards the west. When the fold developed, the rocks were so plastic that mica flakes and quartz grains within the quartzite bands recrystallised with their long axes parallel to the axial line of the fold ; the axial line, the *b*-tectonic axis, is the intermediate direction of stress in the fold. Thus, on the bedding planes of the quartzites is a pronounced lineation, which is caused by the parallelism of the mica flakes and quartz grains (Plate III. (a)). The pitch of the lineation indicates the pitch of the axial line of the main fold.



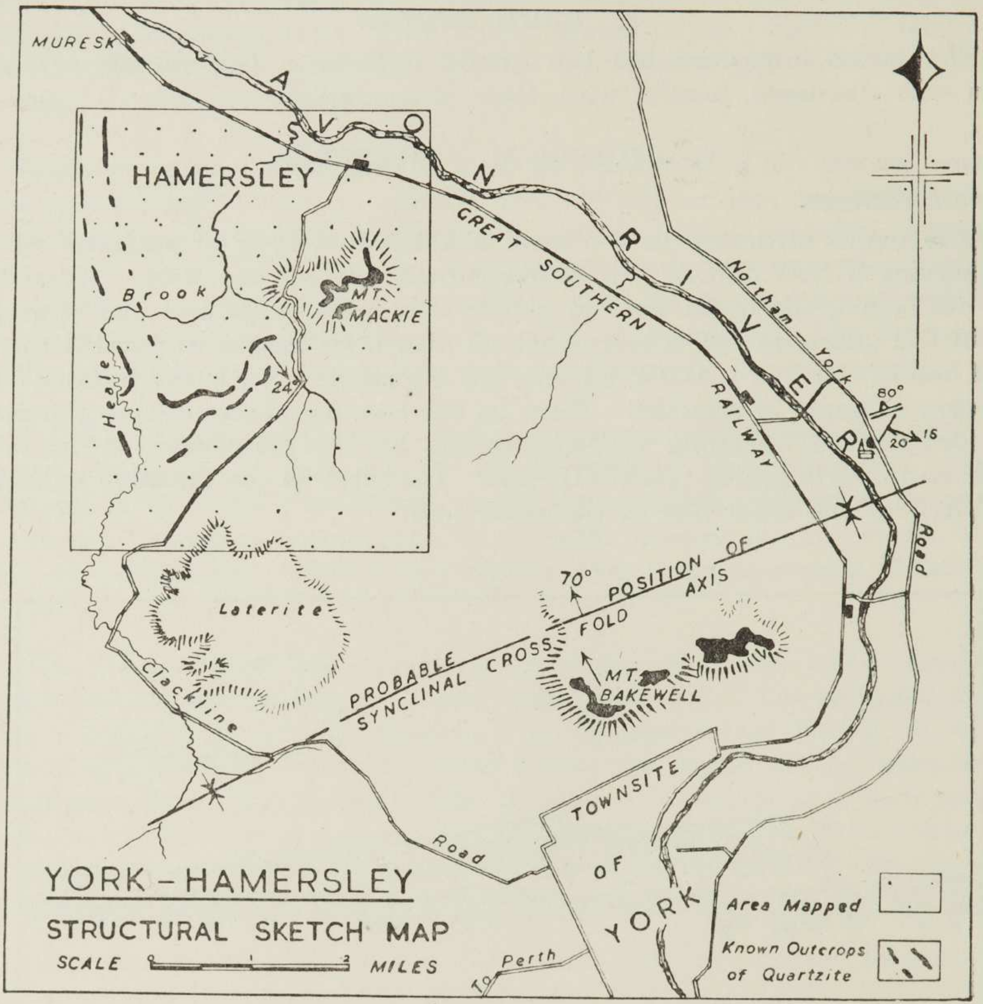
Text Figure 7.

Mt. Bakewell, near York, from the north-east.

The crests of the hills are composed of quartzite which dips at approximately 10° to the north-west towards Mt. Mackie. At the foot of the distant escarpment lies the town of York. The line of trees in the middle distance marks the bed of the Avon River which flows from the left to right.

(Drawn from a photograph by the author.)

The main N.N.W.-S.S.E. folding is buckled by a series of E.N.E.-W.S.W. crossfolds. Consequently the *b*-lineation in the Hamersley Area now pitches to the south-east at an average of 24°. This places the area on the south limb of an anticlinal crossfold with the anticlinal crossfold axis to the north and the synclinal crossfold axis to the south. Mt. Bakewell, near the township of York, and 5 miles to the south of Hamersley, is capped by quartzite which pitches approximately 10° north-west towards Mt. Mackie (text fig. 7). In a quarry near a small Church at Wilberforce, 6 miles from York on the Northam-York Road, the pitch of the lineation in the quartzites is 16° to the south-east (text fig. 8). The synclinal crossfold axis is apparently situated between the church and Mt. Bakewell.



Text Figure 8.

Structural sketch-map, Hamersley to York.

Showing the approximate position of the crossfold axis between Mt. Mackie and Mt. Bakewell.

The crossfolding, while probably part of the same orogeny, occurred later than the main folding, for, whilst plastic structures such as drag folds and *b*-lineations are associated with the major fold, the crossfold has only a fracture cleavage associated with it. The fracture cleavage, where measured at Hamersley and at the church, has an average strike of 71° and dip of 70° to the N.N.W. These might represent the strike and dip of the axial plane of the crossfold.

Structure and Facies Change.

The structure section (Plate I.) shows two thin beds of quartzite which dip steeply in the western part of the area, are relatively flatlying in the centre, and coalesce in a great mass of quartzite to the east of Mt. Mackie. Two interpretations may be made :—

1. The beds may be the same bed on opposite limbs of a very tight isoclinal fold with its apex at Mt. Mackie.
2. The structure may be considered as a simple box-fold type anticline in which the apparent isoclinal fold may be explained as a facies change.

The former was discarded because such a fold would require at least two orogenies for its formation and because any attempt at a structural interpretation of the area is hampered by the dearth of primary sedimentary structures in the well-bedded quartzites which would determine the order of super-position. The quartzites are so pure that the few outcrops, on which current bedding could be faintly discerned, proved to be undecipherable. Lacking confirmation, by means of primary structures, hypotheses implying overturning, *e.g.*, the isoclinal fold theory, cannot be proven other than by the doubtful criterion of dragfolding.

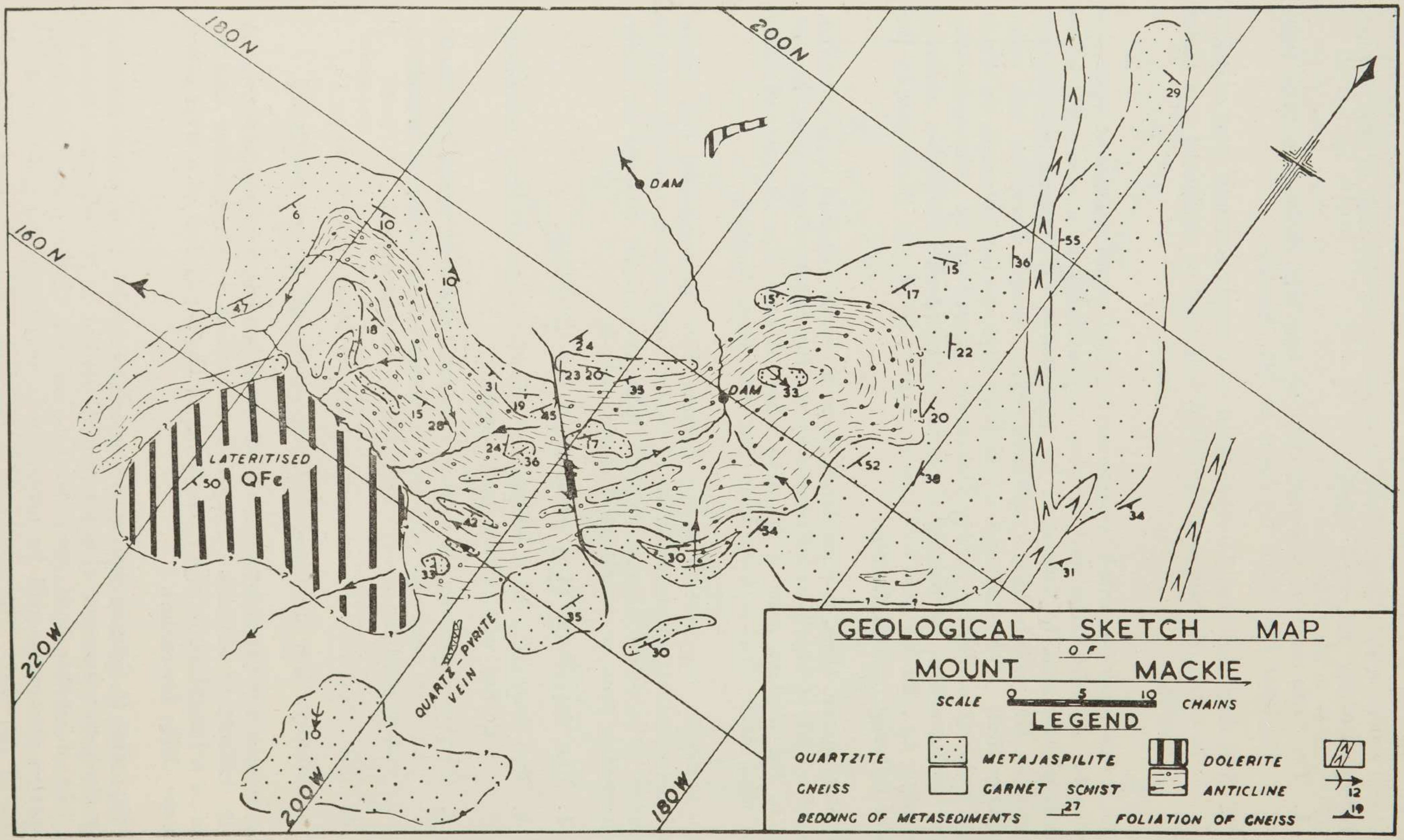
The structure, then, is considered to be a simple box-fold type anticline, the western limb of which, as delineated by the two bands of quartzites, is overturned in the western part of the area where it now dips at approximately 70° to the east. The eastern limb has not been located.

As noted in the section above dealing with petrogenesis, the arkose formation contained numerous lenses of varied composition. It may thus be interpreted as a shallow-water deposit with very rapid changes in facies. The succession was probably as follows :—

1. The deposition of a great thickness of arkose.
2. The formation of a widespread discontinuous sheet of sandstone, together with shales and cherts.
3. Further deposition of arkose, except in the area where Mt. Mackie is now situated. In this region a thick layer of sandstone, associated with clays and cherts, was deposited.
4. The deposition of another sandstone layer, cherts, etc.
5. Finally, the uninterrupted deposition of arkose continued.

The reason for the deposition of the sandstone in two semi-continuous bands is difficult to explain. They may represent a transgression and regression of a beachline, or the meandering of the sandy bed of a river across an arkosic delta formation.

Thus, owing to a facies change, the quartzite marker beds, which delineate the west limb and the crest of the box-fold, die out at Mt. Mackie. Because of this loss of marker beds, very careful mapping of the planar and linear structures in the gneiss will be necessary to determine the position of the east limb of the fold. The quartzite at Mt. Bakewell may represent a continuation of the same sandstone facies and the mapping of that area will probably assist in the determination of the position of the east limb.



Text Figure 9.

Geological sketch-map of Mount Mackie.

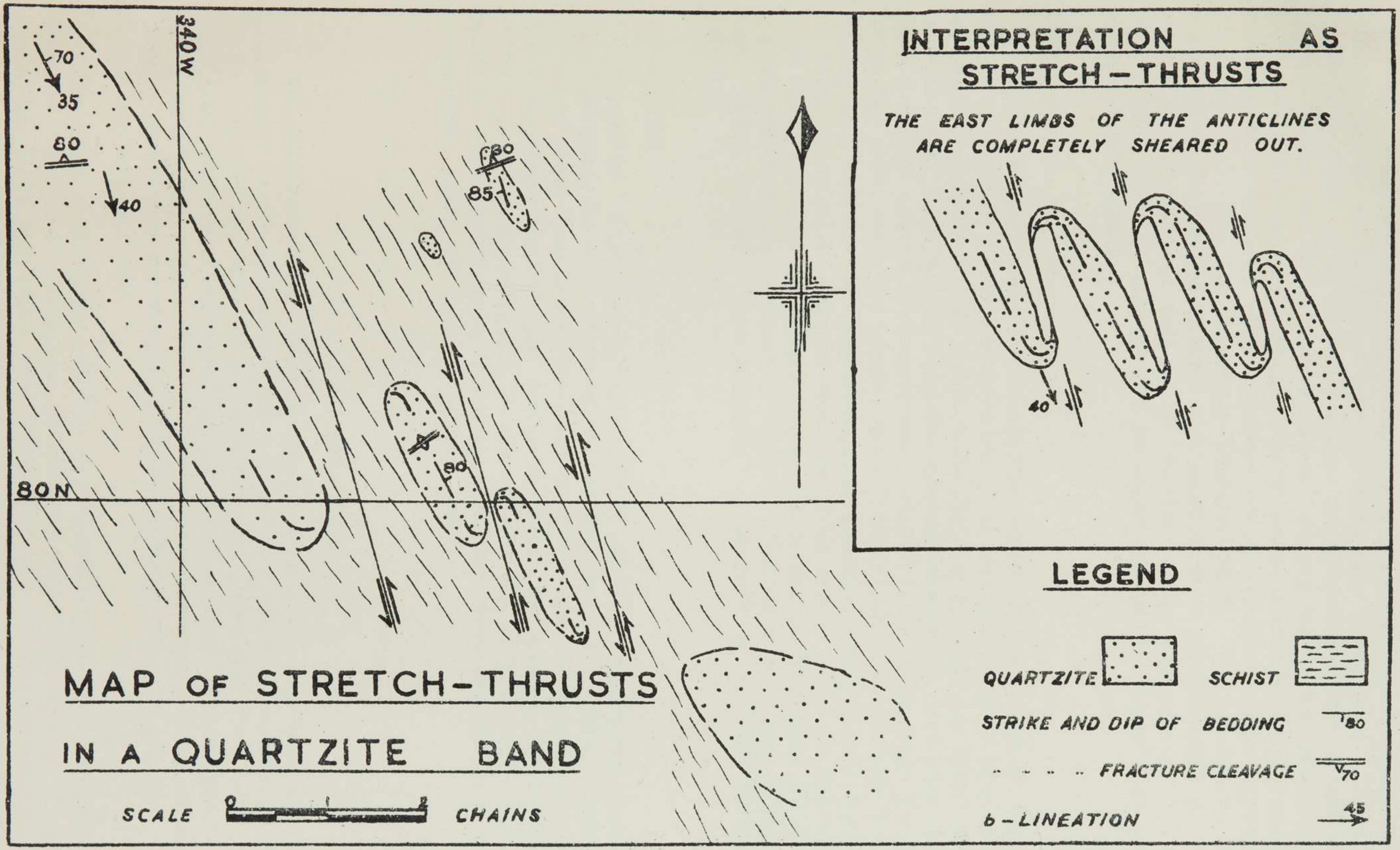


Figure 10.

En echelon lenses of quartzite and their interpretations as stretch-thrusts.

Mt. Mackie (Text fig. 9).

The alternating bands of quartzite and garnet-sillimanite schist at Mt. Mackie provide the best outcrops in the Hamersley Siding Area. There, the quartzites stand up as resistant ridges, approximately 100 ft. above steep valleys carved out of the weaker schists. Among the blocky quartzite outcrops are numerous exposures of bedding planes from which strike and dip readings were obtained. These showed minor contortions superimposed on the major synclines and anticlines developed there. The contortions were very pronounced in the vicinity of a small fault or stretch-thrust which is shown in the centre of text fig. 9. In the western part of Mt. Mackie, a large amphitheatre of quartzite has developed around the exposed margin of a south-pitching syncline.

Stretch-thrusts.

At the western corner of the boxfold, which outcrops at (80 N, 340 W), the lower quartzite is extremely contorted. It outcrops in a series of *en echelon* lenses in each of which the strike of the bedding parallels the length of the lens (text fig. 10). At first sight the quartzite appears to have been broken into lenses by a series of thrust-faults. However, the deformation occurred when the rocks were in a plastic, not a brittle, state and therefore folding, rather than faulting, is the more likely mode of origin of their present structure. A closer examination revealed that the strike curved round at the end of each lens. Thus the lenses may be interpreted as the alternate limbs of a closely packed series of folds from each of which one limb has been completely sheared out. These are the " stretch-thrusts " mentioned by Conolly (1946, pp. 166–7).

Shear zones.

Lenses of " finely crushed quartzites "—silicified shear zones—occur in lines traversing the area. Near (80 N, 360 W), a bedded quartzite is deflected by one of these shear zones, which are probably caused by re-adjustments of the rock mass after the main spasm of folding had passed, but before the rocks had lost their plasticity. To the south of Mt. Mackie, several lenses of quartzite have lunate ends, indicating that they were also involved in re-adjustments while still in a semi-plastic state.

VI. CONCLUSIONS.

The Hamersley Area is composed of a series of Pre-Cambrian metasedimentary rocks—quartzites, mica schista and gneisses—similar to those of the Jimperding Series of the country near Toodyay. They have been isoclinally folded and subjected to high grade regional metamorphism as have the Toodyay rocks ; but more fieldwork is necessary in the intervening country before detailed correlation may be effected with the previously described Jimperding Series.

The most contentious problem in connection with these rocks is the origin of the gneisses—these have previously been considered to be of igneous origin, but in the Hamersley Area various factors point to a metasedimentary origin for the major part of them : (1) fluorescence tests indicate that felspathisation (or the effects of magmatism) occur only near the granite mass to the west, (ii) wherever observed, the gneiss is conformable with the quartzites and schists, and (iii) thin beds such as the quartzites could not preserve continuity were they involved in a large-scale magmatic intrusion such as that required to explain all the gneiss as a consolidated magma. If this conclusion be valid, the various quartzite, schist, and metajaspilite lenses in the gneiss must be explained as the metamorphic equivalents of quartzose, pelitic, and cherty facies in an arkose, instead of lenses of original country rock which have escaped granitisation or complete assimilation by a magma.

The granite to the west, which has apparently assimilated the country rock during its emplacement, displays intrusive relationships towards the older rocks—under the influence of " emanations," probably with admixtures of actual granite magma, a part of the pre-existing rocks was converted into a mobile granite mass which intruded the gneisses, quartzites and schists. The appinites are apparently related to this younger granite but their two distinct modes of occurrence are puzzling. Until detailed work is undertaken on other exposures of these rocks, such as those near Mt. Bakewell or at Muresk, any attempts at assigning an origin to them must be largely guesswork.

The quartz-dolerites and laterite are normal types, discussion of which has been presented in many previous papers on the Geology of parts of Western Australia.

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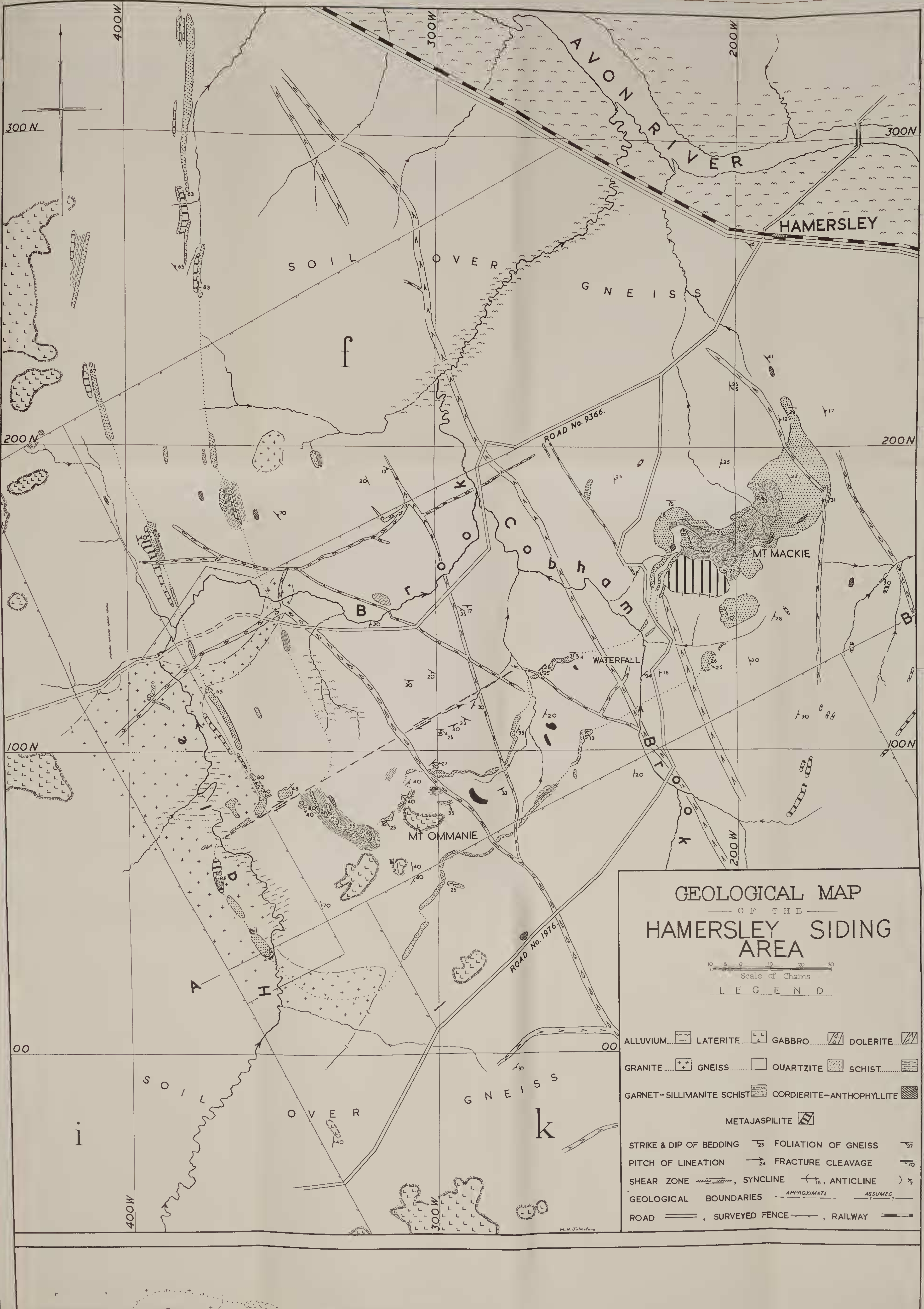
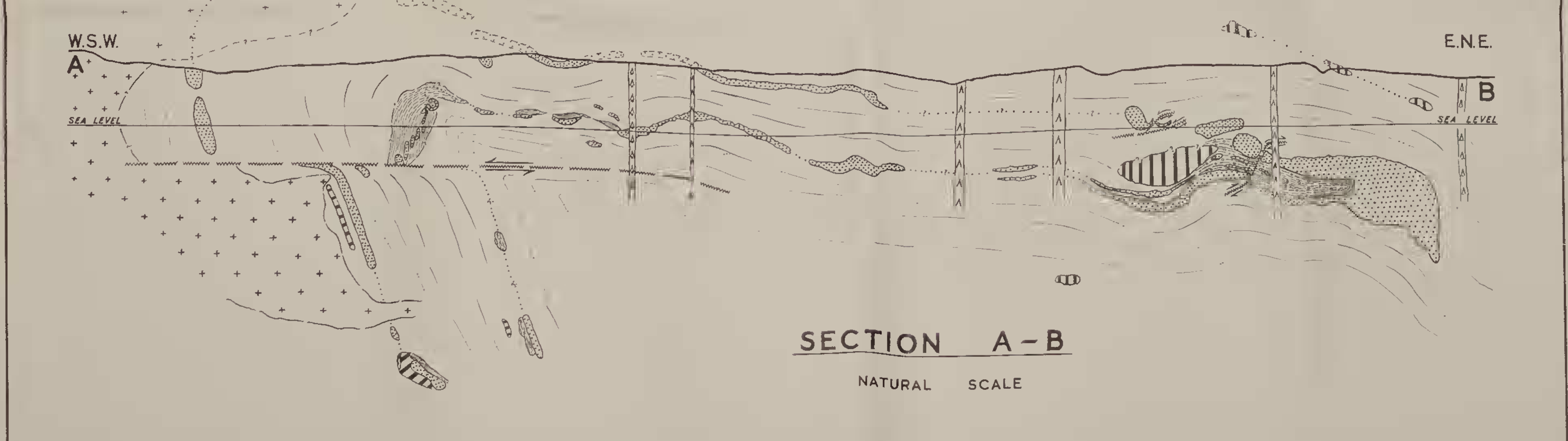


GEOLOGICAL MAP OF THE HAMERSLEY SIDING AREA



SECTION A-B

NATURAL SCALE